BARYOGENESIS MOTIVATED ON STRING CPT VIOLATION

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We discuss a mechanism for generating the baryon asymetry of the Universe that involves a putative violation of CPT symmetry arising from string interactions.

1 Introduction

In this contribution we describe a baryogenesis mechanism based on a possible violation of the CPT symmetry that arises in string field theory [1]. Our mechanism is based on the observation that certain string theories may spontaneously break CPT symmetry [2] and Lorentz invariance [3,4]. If CPT and baryon number are violated then a baryon asymmetry can be generated in thermal equilibrium [5,6]. We assume that the source of baryon-number violation is due to processes mediated by heavy leptoquark bosons of mass M_X in a generic GUT whose details are not important in our discussion.

The CPT-violating interactions are shown to arise from the trilinear vertex of non-trivial solutions of the field theory of open strings and in the corresponding low-energy four-dimensional effective Lagrangian via couplings between Lorentz tensors N and fermions [2]. The CPT and Lorentz invariance violation appears when components of N acquire non-vanishing vacuum expectation values $\langle N \rangle$. For simplicity, we consider here only the subset of the CPT-violating terms leading directly to momentum- and spin-independent energy shift of particles relative to antiparticles that are diagonal in the fermion fields, ψ, and involve expectation values of only the time components of N [1,2]:

$$\mathcal{L}_I = \frac{\lambda \langle N \rangle}{M_S^k} \overline{\psi} (\gamma^0)^{k+1} (i\partial_0)^k \psi + h.c. + ... \quad , \tag{1}$$

where λ is a dimensionles coupling constant and M_S a string mass scale which is presumebly close to the Planck scale. Since no large CPT violation has been observed, the expectation value $\langle N \rangle$ must be suppressed in the low-energy effective theory. The suppression factor is some non-negative power l of the ratio of the low-energy scale m_l to M_S, that is $\langle N \rangle = (m_l/M_S)^l M_S$. Since each factor of $i\partial_0$ also provide a low-energy suppression, the condition $k + l = 2$ corresponds to the dominant terms [2]. Assuming that each fermion represents a standard-model quark of mass m_q and baryon number 1/3, then the energy splitting between a quark and its antiquark arising from Eq. (1) can be viewed as an effective chemical potential,

$$\mu \sim \left(\frac{m_l}{M_S} \right)^l \frac{E^k}{M_S^{k-1}} \quad , \tag{2}$$

driving the production of baryon number in thermal equilibrium.

The equilibrium phase-space distributions of quarks q and antiquarks $\bar{q}$ at temperature T are $f_q(\vec{p}) = (1+e^{(E-\mu)/T})^{-1}$ and $f_{\bar{q}}(\vec{p}) = (1+e^{(E+\mu)/T})^{-1}$, respectively, where $\vec{p}$ is the momentum and $E = \sqrt{m_q^2 + p^2}$. If g is the number of internal quark degrees of freedom, then the difference between the number densities of quarks and antiquarks is

$$n_q - n_{\bar{q}} \quad = \quad \frac{g}{(2\pi)^3} \int d^3p \; [f_q(\vec{p}) - f_{\bar{q}}(\vec{p})] \quad . \tag{3}$$

The contribution to the baryon-number asymmetry per comoving volume is given by $n_B/s \equiv (n_q - n_{\bar{q}})/s$, and on its turn the entropy density $s(T)$ of relativistic particles is given by

$$s(T) = \frac{2\pi^2}{45} g_s(T) T^3 \quad , \tag{4}$$

where $g_s(T)$ is the sum of the number of degrees of freedom of relativistic bosons and fermions at temperature T.

As shown in Ref. [1] it follows from eqs. (3) and (4) that each quark generates a contribution to the baryon number per comoving volume of

$$\frac{n_q - n_{\bar{q}}}{s} \sim \frac{45 g}{2\pi^4 g_s(T)} I_k(m_q/T) \quad , \tag{5}$$

where

$$I_k(r) = \int_r^\infty dx \, \frac{x\sqrt{x^2 - r^2}\,\sinh(\lambda_k x^k)}{\cosh x + \cosh(\lambda_k x^k)} \tag{6}$$

and

$$\lambda_k = \left(\frac{m_l}{M_S}\right)^l \left(\frac{T}{M_S}\right)^{k-1} \quad . \tag{7}$$

The relevant case for baryogenesis is $k = 2$ and $\lambda_2 = T/M_S$. A good estimate of the integral $I_2(m_q/T)$ can be obtained by setting m_q/T to zero, since fermion masses either vanish or are much smaller than the decoupling temperature T_D and hence $I_2(m_q/T) \approx I_2(0) \simeq 7\pi^4 T/15 M_S$. This yields for six quark flavours a baryon asymmetry per comoving volume given by [1]

$$\frac{n_B}{s} \simeq \frac{3}{5}\frac{T}{M_S} \quad . \tag{8}$$

Therefore for an appropriate value of the decoupling temperature T_D, the observed baryon asymmetry of the Universe $n_B/s \simeq 10^{-10}$, can be obtained provided the interactions violating baryon number are still in thermal equilibrium at this temperature. In estimating the value of T_D, dilution effects must be taken into account.

A particularly relevant source of baryon asymmetry dilution are the baryon violating sphaleron transitions. These processes are unsuppressed at temperatures above the electroweak phase transition [7]. Assuming the GUT conserves the quantity $B - L$, B and L denoting the total baryon- and lepton-number densities, sphaleron-induced baryon-asymmetry dilution occurs when $B - L$ vanishes [8] and hence [1]:

$$\frac{n_B}{s} \simeq \left(\frac{m_L}{T_W}\right)^2 \frac{T_D}{M_S} \quad . \tag{9}$$

Taking the heaviest lepton to be the tau and the freeze-out temperature T_W to be the electroweak phase transition scale, then the baryon asymmetry generated via GUT and CPT violating processes is diluted by a factor of about 10^{-6}. Thus, the observed value of the baryon asymmetry can be reproduced if, in a GUT model where $B - L = 0$ initially, baryogenesis takes place at a decoupling temperature $T_D \simeq 10^{-4} M_S$, followed by sphaleron dilution [1]. This value of T_D is shown to be close to the GUT scale and leptoquark mass M_X, as required for consistency.

In the less interesting case of GUT models where initially $B - L \neq 0$, as already mentioned, spharelon dilution effects are not important, however other mechanisms such as for instance dilaton decay [9,10], can set the baryon asymmetry (8) to the observed value.

We point out that the decoupling temperature $T_D \simeq 10^{-4} M_S$ is sufficient low for our baryogenesis mechanism to be compatible with string-inspired primordial supergravity inflationary models [11,12].

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